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# A PROPOSED METHOD OF FSK GENERATION AND DEMODULATION FOR THE DREO RADIO TEST BED (U)

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DEFENCE RESEARCH ESTABLISHMENT OTTAWA

TECHNICAL NOTE 90-13



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# A PROPOSED METHOD OF FSK GENERATION AND DEMODULATION FOR THE DREO RADIO TEST BED (U)

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*Electronic Warfare Division*



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## ABSTRACT

A Radio Test Bed (RTB) is currently being developed for DREO under contract. The test bed is to serve as a powerful general purpose laboratory instrument for the generation and demodulation of conventional communications signals found in the tactical environment. The system will interface with the DREO Communications Jamming Simulator to allow jamming studies to be performed on various signals. The system will have the capability of generating and demodulating the following signals: AM, FM, USB, and LSB.

A method has been devised to incorporate the generation and demodulation of data modulated Frequency Shift Keyed (FSK) signals into the RTB. The modulation technique involves using a baseband data signal to directly frequency modulate an RF carrier. Demodulation is achieved by using the FM demodulator of the RTB. Some signal conditioning is required, but the FSK generation and demodulation scheme has the capability of being easily and inexpensively implemented in the RTB while it is still under construction. The proposed method has been tested at DREO with excellent results.

## RÉSUMÉ

Un sous–traitant développe présentement au CRDO un banc d'essai radio (BER). Le banc d'essai sera un puissant instrument de laboratoire tout–usage pour la production et la démodulation de signaux simples provenant d'un environnement tactique. Le système aura une interface avec le simulateur de brouillage de communications du CRDO afin de permettre l'étude de brouillage sur divers signaux de communication. Le système pourra produire et démoduler les signaux suivants: AM, FM, bande latérale supérieure et bande latérale inférieure.

Le BER comprend une méthode de production et de démodulation de signaux modulés par déplacement de fréquences et par les données. La technique de modulation consiste à moduler directement la porteuse radio avec les signaux de la bande de base. La démodulateur FM du BER effectue la démodulation. Bien qu'elle requiert un peu de traitement de signal, la methode de production et de démodulation par déplacement de fréquences peut facilement, et à peu de frais, être intégrée au BER au moment de la construction. Les tests de la méthode proposée par la CRDO ont produit d'excellents résultats.

## EXECUTIVE SUMMARY

A Radio Test Bed (RTB) is currently being developed for DREO under contract. The test bed is to serve as a powerful general purpose laboratory instrument for the generation and demodulation of conventional communications signals found in the tactical environment. The system will also interface with the DREO Communications Jamming Simulator (CJS). It will allow a voice or data signal to be taken from the CJS and modulated. A jamming signal from the CJS can optionally be added to the RF signal. The resulting signal will then be demodulated in the RTB. The recovered data or voice can then be compared with the original modulating waveform and the bit error rate or articulation index will be computed by the CJS. This will allow studies of the effects of various jamming waveforms on different communications signals to be made.

One of the desired modulations for the RTB is data modulated Frequency Shift Keyed (FSK) modulation. This type of modulation is used extensively by the Canadian Forces and other countries for the transmission of tactical data on VHF. Incorporation of FSK into the RTB would allow studies to be made of effective jamming techniques for FSK modulation, and would also allow studies to be made of the susceptibility of FSK modulation to certain forms of jamming.

This document clarifies the type of FSK desired in the RTB, and proposes a method of implementing the FSK generation and demodulation in the RTB. This method has the capability of being inexpensively implemented in the RTB while it is still under construction. The proposed method has been tested extensively at DREO with excellent results.

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## 1.0 INTRODUCTION

A Radio Test Bed (RTB) is currently being developed for DREO under contract. The test bed is to serve as a powerful general purpose laboratory instrument for the generation and demodulation of conventional communications signals found in the tactical environment. The system will also interface with the DREO Communications Jamming Simulator (CJS). It will allow a voice or data signal to be taken from the CJS and modulated. A jamming signal from the CJS can optionally be added to the RF signal. The resulting signal will then be demodulated in the RTB. The recovered data or voice can then be compared with the original modulating waveform and the bit error rate or articulation index will be computed by the CJS. This will allow studies of the effects of various jamming waveforms on different communications signals to be made. The system will have the capability of generating and demodulating the following signals: AM, FM, USB, and LSB.

One type of transmission which is desirable for the RTB is a data modulated Frequency Shift Keyed (FSK) signal. This modulation is used extensively in both civilian and military communications for the transmission of data. A method has been devised to incorporate the generation and demodulation of FSK into the RTB. The modulation technique involves using a baseband data signal to directly frequency modulate the RF carrier. Demodulation is achieved by using the FM demodulator of the RTB with some additional signal conditioning.

This document clarifies the type of FSK desired in the RTB, and proposes a method of implementing the FSK generation and demodulation in the RTB. This method has the capability of being inexpensively implemented in the RTB while it is still under construction. The method of FSK modulation and demodulation proposed in this document has been tested extensively at DREO with excellent results. The demodulator designed for these tests can be used as a very inexpensive way of extending the demodulation capabilities of a Watkins Johnson 8617B, or any receiver which provides DC coupled FM demodulator output, to allow FSK demodulation.

## 2.0 DISCUSSION OF FSK MODULATION

Frequency Shift Keyed modulation can be viewed as a special case of frequency modulation in which the baseband modulation signal is a bipolar Non Return to Zero (NRZ) waveform which represents the digital information to be transmitted [1]. When this NRZ waveform is used to frequency modulate an RF carrier, the resulting signal switches between two frequencies designated the mark and space frequencies.

Various standards exist for the transmission of data using FSK. For binary signaling up to 300 bits/sec over commercial telephone channels, the usual choice of transmit frequencies is 1070 Hz (space) and 1270 Hz (mark), or 2025 Hz (space) and

2225 Hz (mark) [2]. This is the Bell 103/113 standard [3]. For higher speed data transfer at 1200 bits/sec, the Bell 202 standard specifies mark and space frequencies of 1200 Hz and 2200 Hz respectively [3]. These types of FSK signals are usually used to allow communication between computers. The channel is at baseband. In other words, the two tones are transmitted directly either over a telephone line or a cable

Often however, it is necessary to transmit an FSK signal over a radio frequency channel. An example of this is the transmission of radioteletype (RTTY). Amateur radio standards for the transmission of Baudot and AMateur Teleprinting Over Radio (AMTOR) RTTY signals usually use a mark to space frequency separation of 170 Hz. The nominal transmitter frequency is arbitrarily designated as the mark frequency. A space condition causes the transmitter to shift down in frequency by 170 Hz. These signals are usually generated by directly frequency modulating a carrier using the data signal, or by using an audio FSK signal (2125 Hz mark and 2295 Hz space) as the input to a single sideband (SSB) transmitter. The former method is called direct FSK and falls into the F1B emissions designation as specified by the 1979 World Administrative Radio Conference (see Appendix A). The latter is designated as J2B. Often the two are indistinguishable and both result in an FSK signal at RF. Above 50 MHz, RTTY signals are sometimes sent by using an audio FSK signal to frequency modulate a carrier. This emission is designated as F2B. The transmitted signal cannot be considered an FSK signal; rather it is a hybrid FSK/FM signal.

NATO standards for the tactical VHF transmission of data at 16 kbps call for an FSK signal with a mark frequency 5 kHz below the center frequency and a space frequency 5 kHz above the center frequency [4]. In other words, the carrier can be considered a frequency modulated carrier with a peak frequency deviation of 5 kHz. It therefore falls into the F1B emissions designation.

Most FSK schemes for transmission over HF or VHF frequencies do not require that the phase of the RF carrier remain continuous during switching. It is only for very high data rates in which bandwidth efficiency becomes a consideration, that continuous phase FSK (CPFSK) is necessary. These FSK schemes are typically used in telecommunications links at microwave frequencies.

Ideally, the RTB should be capable of generating and demodulating any of the standard HF/VHF/UHF FSK signals of the F1B or J2B type. It is not necessary for the FSK to be continuous phase. The RTB should offer the flexibility to generate and demodulate a nonstandard FSK signal. This may involve changing the mark to space frequency separation to a nonstandard value. It would also be desirable that the output data be provided in both true and inverted format. This would allow for the possibility of the mark and space frequencies being reversed (mark frequency above the space frequency, or visa versa). Data rates should be variable from 10 bit per second (bps) to 19200 bps.

## 3.0 PROPOSED FSK GENERATION AND DEMODULATION FOR THE RTB

A system configuration diagram for the RTB, as it is presently being built, is shown in Figure 1 [5]. The transmitter side of the test bed consists of a Hewlett Packard (HP) 8657A Synthesized Signal Generator, and a Single Sideband (SSB) modulator. AM or FM modulation is achieved by using the external modulation feature of the HP synthesizer. This allows AM or FM signals to be generated with carrier frequencies ranging from approximately 100 kHz to 1040 MHz. The SSB modulator is a custom built unit allowing the generation of upper or lower single sideband modulation with the carrier ranging from 2 – 500 MHz. A jamming signal from the DREO Communications Jamming Simulator (CJS) can optionally be added to the RF signal. The receiver side of the testbed consists of a Watkins Johnson 8617B receiver with frequency extension options (2 – 1100 MHz). The receiver is capable of the demodulation of AM, FM, CW, USB and LSB signals. Baseband modulation inputs and demodulated outputs are routed by a programmable crosspoint switch. The entire system is completely controlled by a computer over a GPIB interface. Software included with the system will provide the user interface for setting up the equipment as desired.

Direct FSK generation in the RTB can be easily achieved by allowing the data signal to directly frequency modulate a carrier through the HP8657A signal generator [6]. The 100 kHz cut off frequency of the modulation input will distort the data signal slightly at higher data rates, but the method has been tested and has been found to work up to a data rate of 19200 bits/sec (See Section 4). Using the data to directly frequency modulate the carrier has the advantage that the user will have complete control over the mark and space frequencies since the peak frequency deviation for the HP8657A signal generator can be programmed by the user. The data signal must be conditioned such that it varies from approximately +1 Volt to – 1 Volt. It must also be DC coupled to the HP8657A otherwise FSK signals with data rates below approximately 300 bits/sec cannot be accurately generated. The FSK signal generated will consist of a mark frequency above the center frequency and a space frequency below the center frequency, each by an amount equal to the selected peak frequency deviation.

The FSK can be demodulated using the FM demodulators of the WJ8617B receiver shown in Figure 1. The receiver has 5 selectable FM demodulators with bandwidths equal to one half of the selected IF bandwidth. The IF bandwidths available are: 6.4 kHz, 20 kHz, 50 kHz, 100 kHz, and 4 MHz. Other IF bandwidths are available as options from Watkins Johnson [7]. Since the FM demodulators provide a DC coupled output, the FSK signal can be demodulated by tuning the WJ8617B receiver to the center frequency of the FSK signal and monitoring the FM Monitor output. This can be accessed from a BNC connector on the back panel of the receiver. The gain of the FM demodulators is set to provide a 1 volt peak to peak signal into a 91 ohm load for a frequency modulated carrier with a peak frequency deviation of 30% of the selected IF bandwidth [7]. The FM demodulated signal will consist of two distinct voltage levels representing the modulated data. Some conditioning can then be performed on this signal to obtain TTL compatible

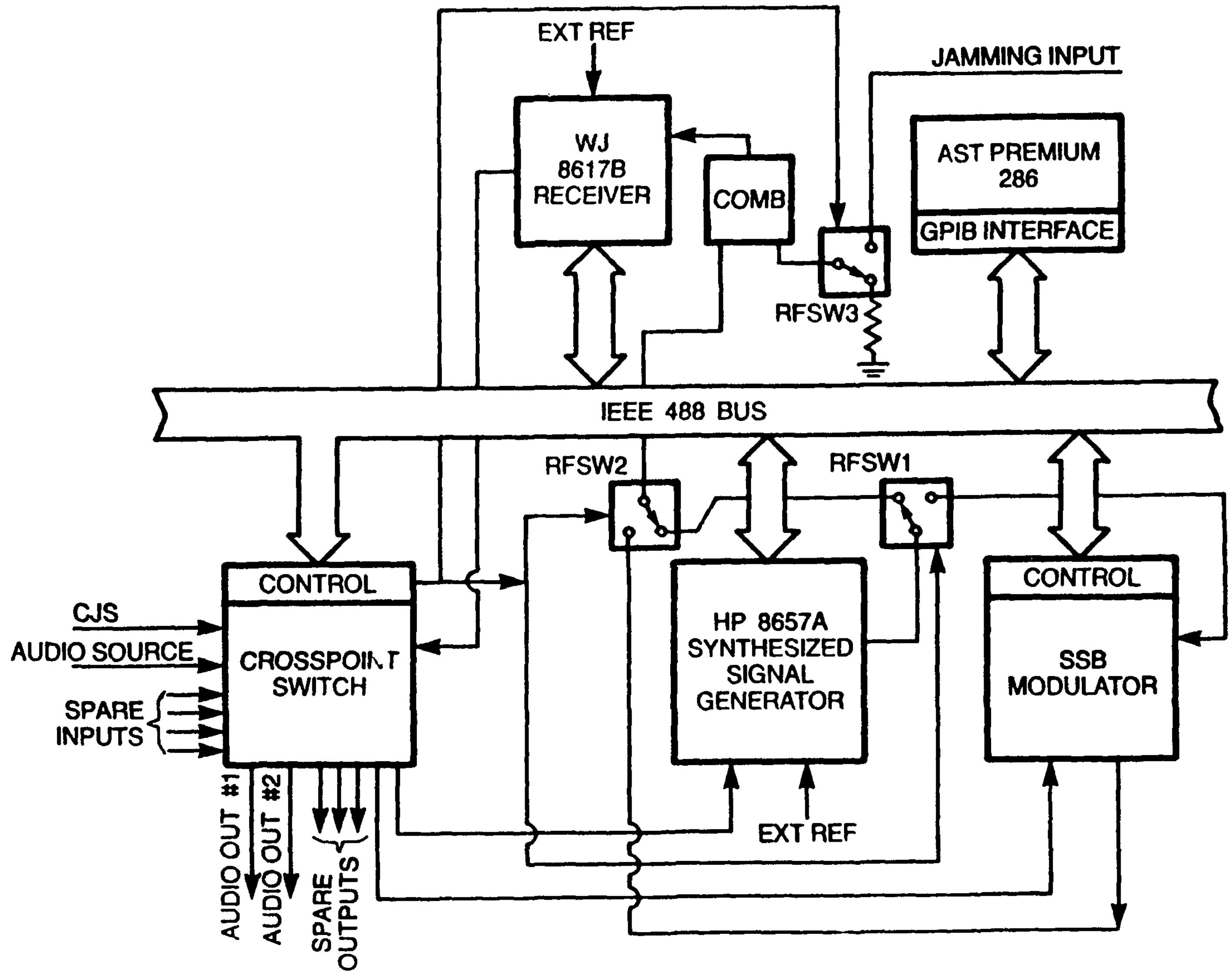


Figure 1: System Configuration Diagram For RTB

data. The IF bandwidth must be chosen to satisfy Carson's rule [8]:

$$BW \geq \Delta f + R/2 \qquad (3.1)$$

where: $\Delta f$ is the peak frequency deviation
R is the data rate

For the bandwidth selection, the data rate is divided by two since the bandwidth efficiency of an NRZ waveform is 2 bits per second/Hz [2]. If the bandwidth determined by Carson's rule is in between two of the available IF bandwidths, the greater bandwidth is usually chosen. In practice however, due to the finite roll–off of the IF filter, the lesser bandwidth may be used. The lesser bandwidth may, in some cases, give better performance since it has a greater output for a given peak frequency deviation.

## 4.0 TESTING OF PROPOSED FSK GENERATION AND DEMODULATION METHOD

### 4.1 Description Of Test Set Up

The method of FSK generation and demodulation described in Section 3 was tested in the Communications Electronic Warfare (CEW) laboratory of DREO. The set up was as shown in Figure 2. An HP8644A synthesizer was used in place of the HP8657A synthesizer used in the RTB. Like the HP8657A, the HP8644A allows an external input to be used to amplitude or frequency modulate a carrier. The specifications for the external modulation input are similar for both synthesizers and both allow DC coupling of the external modulation input. The WJ8617B receiver used for the testing had a frequency range of 20 – 1100 MHz. It did not have the frequency extension option allowing operation down to 2 MHz. The conditioning circuitry used is shown in Figure 3.

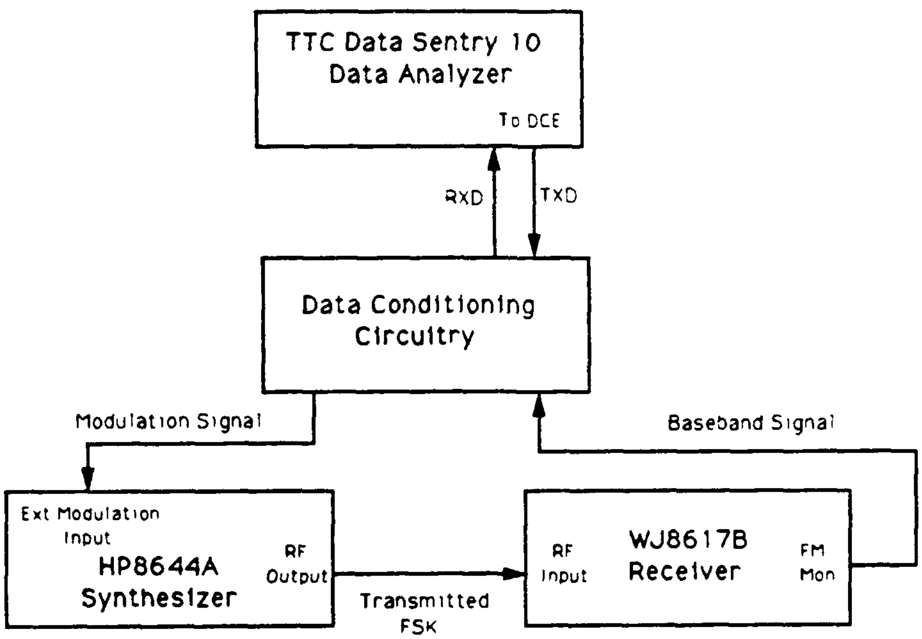


Figure 2:
Set Up For Testing Proposed FSK Generation and Demodulation Method

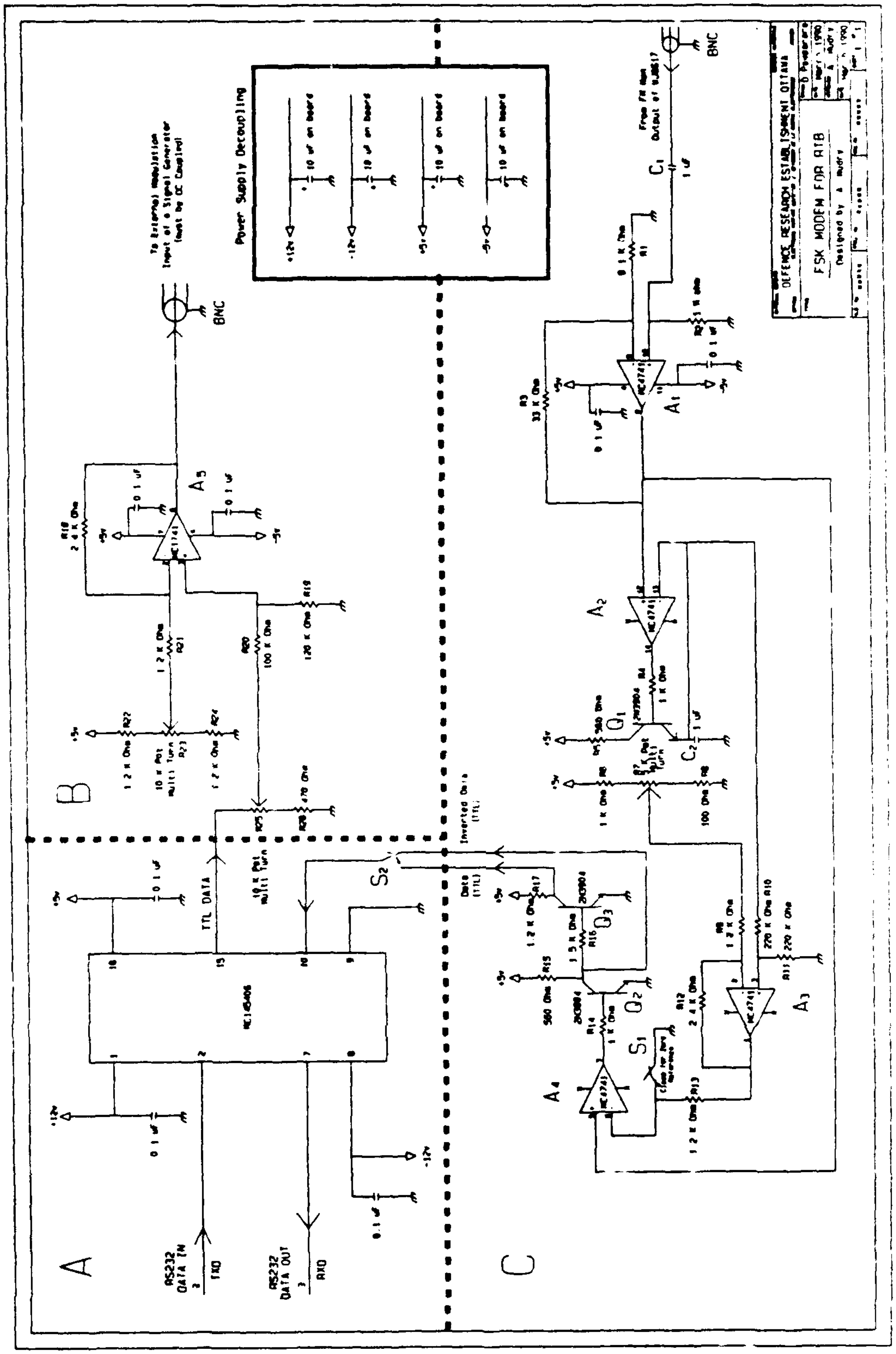

Figure 3:
Data Conditioning Circuitry For FSK Modulation and Demodulation

The Telecommunications Techniques Corporation (TTC) Data Sentry data analyzer, shown in Figure 2, was configured as Data Terminal Equipment (DTE). A full duplex (FDX) link was established. The FSK modem was treated as Data Communications Equipment (DCE). Option 08 in the list of auxiliary functions was used to disable the full RS232 protocol [9]. The data was transmitted asynchronously, using 8 bits with no parity, and 1 stop bit. An internal 12 tap feedback register was used to generate a pseudo-random sequence. The TXD pin of the appropriate output of the data analyser (labelled "To DCE") was used as the input to the conditioning circuitry shown in Figure 3.

Section A of the circuitry provided conversion between RS232 signal levels and TTL signal levels, and visa versa. This was done with an MC145406 RS232 interface chip.

The TTL data was then attenuated and level shifted in Section B of the circuitry. $R_{23}$ (offset) and $R_{25}$ (attenuation) were adjusted so that the data signal at the external modulation input of the HP8644A synthesizer varied between + 1 Volt and − 1 Volt.

The HP8644A synthesizer was adjusted for center frequency, peak frequency deviation, and signal amplitude. The WJ8617B receiver was then tuned to the transmitted frequency. The Automatic Gain Control (AGC) of the WJ8617B was enabled and the Automatic Frequency Control (AFC) was disabled. The IF filter bandwidth was set using the criteria discussed in Section 3. The FM demodulation mode of the WJ8617 was used. The baseband output of the FM demodulator, labelled "FM Mon", was used as the input to the demodulator portion of the circuit shown in Figure 3 (Section C).

In the demodulator portion of Figure 3, the first op amp stage ($A_1$) forms a noninverting high pass filter with a cut off frequency of $1/2\pi$ rad/sec [10]. This is needed to block the DC component of the demodulated signal which results if the receiver is tuned slightly off the transmitted frequency. This would be expected in a true operating environment. The second op amp stage ($A_2$) performs an envelope detection of the data signal. An offset can be added to this envelope by setting $R_7$ to the desired value. The offset addition is performed by the third op amp stage ($A_3$). The shifted envelope can then be used as the decision threshold for op amp $A_4$. This type of threshold is needed in cases where the tuned frequency of either the transmitter or receiver is unsteady. The threshold will then follow minor variations in the demodulated signal level resulting in better bit error rate performance. A resistor in parallel with $C_2$ may be needed depending on the rate of variation. This feature was not tested extensively as the tuned frequencies of both the HP synthesizer and the WJ receiver in the RTB are very steady. For normal operation of the RTB a zero reference for $A_4$ will be used. This will avoid the problem of providing a variable discharge resistor. Transistors $Q_2$ and $Q_3$ provide the output data in either true or inverted TTL format as indicated in Figure 3. Both the true and inverted data are required since, as discussed in Section 2, the mark frequency could be arbitrarily above or below the space frequency. Also, because of the mixing done within the WJ receiver for tuned frequencies above 500 MHz, the mark and space frequencies are reversed at the demodulator. The inverted data is needed to correct this.

TTL data from the demodulator part of the circuit was then converted to RS232 levels, and sent to the RXD pin of the data analyzer. This completed the FDX loop for the test, allowing BER measurements to be made. Bit error rates were measured for FSK transmitted at various frequencies, peak frequency deviations and amplitudes. The results obtained are shown in Table 1. $S_1$ was closed for all measurements and a zero

# TABLE 1:
# MEASURED BIT ERROR RATES

| Center Frequency (MHz) | Amplitude (dbm) | Peak Frequency Deviation | Data Rate (Bits/Sec) 50 | 100 | 300 | 600 | 1200 | 2400 | 4800 | 9600 | 19200 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 22.36 | -70.0 | 200 Hz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | — | — | — |
| | | 500 Hz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | — |
| | | 1 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ |
| | | 2 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ |
| | | 5 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ |
| | | 10 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ |
| | | 25 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ |
| | | 50 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ |
| | | 75 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ |
| | | 100 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ |
| 100.26 | -70.0 | 200 Hz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | — | — | — |
| | | 500 Hz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ |
| | | 1 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ |
| | | 2 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ |
| | | 5 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ |
| | | 10 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ |
| | | 25 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ |
| | | 50 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ |
| | | 75 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ |
| | | 100 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ |
| 950.14 | -70.0 | 200 Hz | $2x10^{-3}$ | $1x10^{-3}$ | $2x10^{-4}$ | $8x10^{-4}$ | $3x10^{-4}$ | $3x10^{-4}$ | — | — | — |
| | | 500 Hz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | — | — |
| | | 1 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ |
| | | 2 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ |
| | | 5 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ |
| | | 10 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ |
| | | 25 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ |
| | | 50 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ |
| | | 75 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ |
| | | 100 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ |
| | -90.0 | 200 Hz | $4x10^{-3}$ | $3x10^{-3}$ | $7x10^{-4}$ | — | — | — | — | — | — |
| | | 500 Hz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $1x10^{-6}$ | — | — |
| | | 1 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | — |
| | | 2 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | — |
| | | 5 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ |
| | | 10 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ |
| | | 25 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ |
| | | 50 kHz | $<10^{-4}$ | $<10^{-4}$ | $<10^{-5}$ | $<10^{-5}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | $<10^{-6}$ | — |
| | | 75 kHz | — | — | — | — | — | — | — | — | — |
| | | 100 kHz | — | — | — | — | — | — | — | — | — |

Note - For data rates of 50 and 100 bits/sec measurements were only made to an accuracy of $10^{-4}$ For data rates of 300 and 600 bits/sec measurements were only made to an accuracy of $10^{-5}$

- A blank entry indicates that synchronization could not be maintained

reference was used for the decision threshold of $A_4$.

## 4.2 Limitations Of Proposed Method

As can be seen from the Table 1, the method of FSK generation and demodulation discussed in Section 3 is capable of excellent results. It must be emphasized that due to time constraints, measurements were performed only to the accuracies indicated in Table 1. A single long term test performed using a data rate of 19,200 bits/sec, a 2 kHz peak frequency deviation, a center frequency of 950.14 MHz, and a signal amplitude of –70.0 dBm, resulted in a measured bit error rate of less than $10^{-8}$. The 20 kHz demodulation bandwidth was used on the WJ8617 receiver.

The main limitations observed in the proposed method resulted when peak frequency deviations of less than 200 Hz were used. Bit error rates rose significantly. This is due to the fact that a 6.4 kHz filter is the smallest available on the WJ8617B. The FM demodulators on the WJ8617B are designed to provide a 1 volt nominal peak to peak signal into a 91 ohm load for a frequency modulated carrier with a peak frequency deviation of 30% of the selected IF bandwidth [7]. Noise within the 6.4 kHz IF bandwidth degrades performance for peak frequency deviations less than 200 Hz. (400 Hz separation between mark and space frequencies). This problem can be inexpensively fixed in a number of ways. The first would be to provide a narrower demodulation bandwidth for the WJ8617B receiver, or use a receiver which provides a DC coupled FM demodulation capability for narrower bandwidths. A second approach would be to use the CW demodulation mode of the WJ8617B to shift the mark and space frequencies to baseband. The resulting audio frequency FSK signal at the demodulator output could then be used as the input to a PLL audio frequency FSK demodulator such as the EXAR XR–2211. Such devices are available as integrated circuits for a few dollars [11].

A second problem occurs when the carrier frequency of the FSK signal exceeds 500 MHz. An extra stage of mixing involved causes mark and space frequencies to become reversed. As a result, the demodulated data is reversed and must be inverted in order to be the same as the original data. A slight degradation in BER performance is also seen for FSK signals having carrier frequencies above 500 MHz and peak frequency deviations greater than 50 kHz. As can be seen in Table 1, synchronization for signals less than –90 dBm becomes difficult. This is probably due to a slight increase in noise figure which occurs due to the extra stage of mixing involved for UHF signals. This increase in noise figure becomes significant

In spite of the limitations in the proposed FSK generation and receiving method, it does meet over 95% of the requirements for the RTB at a fraction of the cost of the proposed alternative methods. It has the capability of being implemented easily, while the RTB is still under construction. The capability to demodulate signals with peak frequency deviations less than 200 Hz could be added to the RTB later fairly easily in house at DREO. Other filter bandwidths are available for the WJ8617B receiver if required.

## 5.0 DISCUSSION OF SYSTEM INTEGRATION

### 5.1 Overall Integration

Since the method proposed in Section 3 is a cost effective solution to the problem of FSK generation and demodulation for the RTB, and meets over 95% of the requirements, it should be implemented immediately while the RTB is still under construction. This will further reduce the costs of providing FSK generation and demodulation capabilities for the RTB. Integration of the proposed FSK method into the RTB should be done as indicated in Figure 4 [12]. Various parts of the conditioning circuitry shown in Figure 3 can be used to implement some parts of the blocks shown in Figure 4. Specific hardware and software concerns associated with the integration are discussed below.

### 5.2 Hardware Concerns

The transmitted data conditioning circuitry required in Figure 4 can be implemented by using Section B of the circuitry shown in Figure 3. The received data conditioning circuitry required in Figure 4 can be implemented by using Section C of the circuitry shown in Figure 3. A zero reference should be used for the decision threshold of $A_4$. Although the demodulator circuitry will not be accessible during normal operation of the RTB, the variable threshold circuitry consisting of $A_2$, $A_3$, $Q_1$, $C_2$, and $R_{4\text{-}13}$ should also be implemented and be switch selectable within the demodulator unit of the RTB. This switch should be closed for normal operation of the RTB providing a zero decision threshold for $A_4$. The switch should not be accessible from the outside panel, nor should it be controllable under software. It will only be required by the user under unusual circumstances in which the transmitted signal does not originate from the HP8657A synthesizer, and has a center frequency which drifts around a certain value. If necessary the user should be able to remove the cover of the demodulator unit and adjust $R_7$ as required. However, it must be emphasized that this in not a usual mode of operation for the RTB and will rarely, if ever be used.

The demodulator board which is being developed for the RTB has a +12 Volt supply [13]. It does not, however, have a –12 Volt supply. One will have to be added, unless an interface chip can be found which will perform the conversion between TTL data and RS232C data and does not require a –12 Volt supply. A –12 Volt supply is usually required for the generation of RS232C signals.

The crosspoint switch must be wired, as indicated in Figure 4 to allow TTL data originating from either an RS232C or MIL–STD–188 device to be used as the input to the HP8657A synthesizer (after conditioning). The crosspoint switch wiring must also support the switching of the demodulated TTL data (either true or inverted) to either the RS232C or MIL–STD–188 conversion circuitry.

### 5.3 Software Concerns

Software implications of the proposed method for FSK generation and demodulation should be minimal. The software should automatically select the IF demodulation bandwidth based on the criteria discussed in Section 3. It should, however, give the user the option of overriding the selected bandwidth and selecting a different data bandwidth. The software should also allow the selection of the output data in either true or inverted format, and should indicate the status both on the PC screen and on the

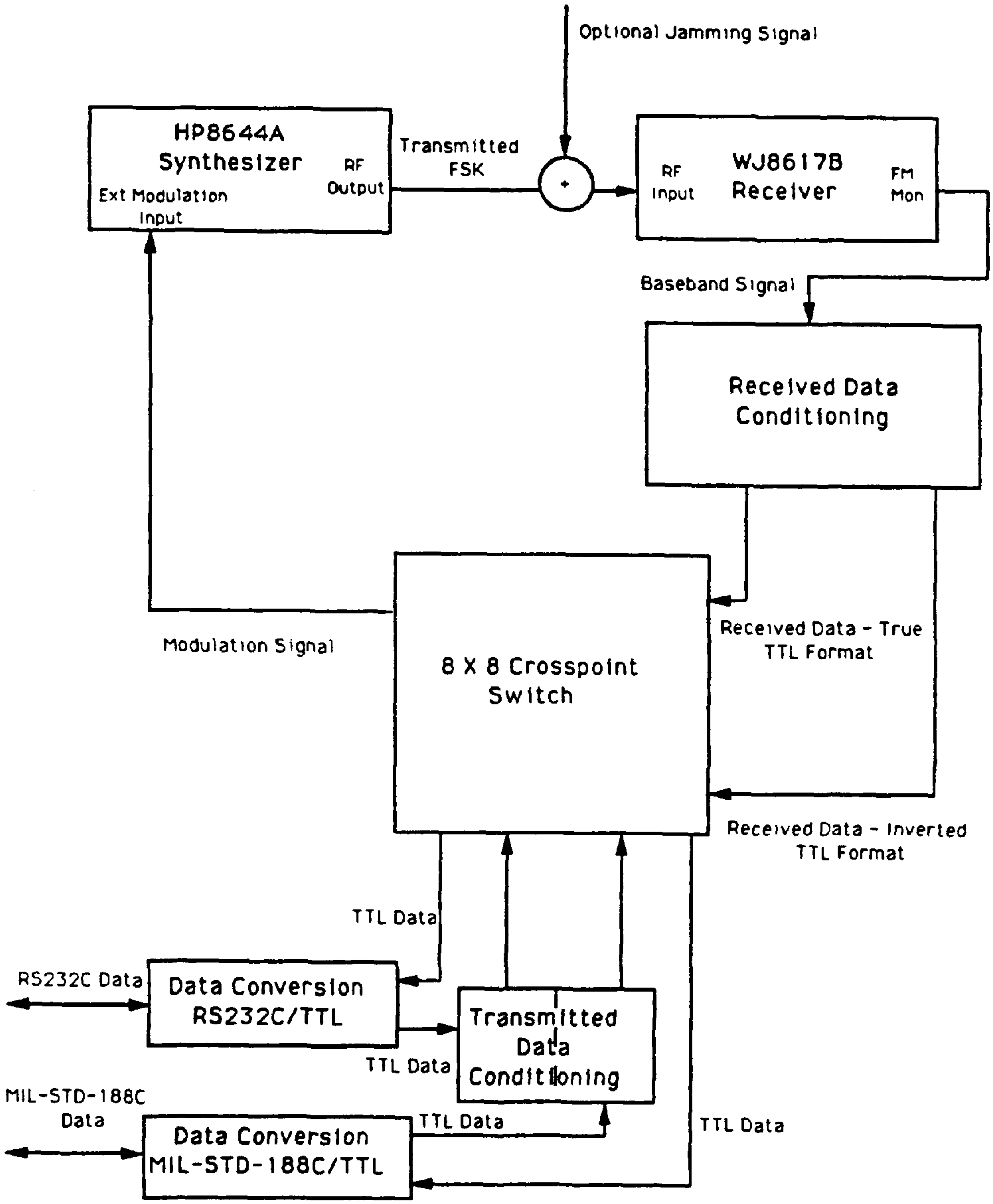


Figure 4:
System Integration Diagram

alpha–numeric display which is currently being used on the control box.

### 5.4 Acceptance Testing

The acceptance testing for the FSK generation and demodulation portion of the RTB should be done in a way identical to the testing which was described in Section 4. Identical center frequencies and a signal amplitude of –70.0 dBm should be used for the acceptance testing. Ten measurements could then be made by choosing at random peak frequency deviations and data rates used in Table 1. Measured bit error rates should not be greater than those indicated in Table 1.

## 6.0 CONCLUSIONS

The method of FSK generation and demodulation proposed in this note for use in the DREO Radio Test Bed is capable of excellent performance. In spite of some limitations, the method meets the requirements for FSK modulation and demodulation in the RTB. It has the capability of being implemented easily and inexpensively, while the RTB is still under construction. Alternatively, the modifications to provide FSK modulation to the RTB could be made in house at DREO following delivery of the system.

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# APPENDIX A

## 1979 World Administrative Radio Conference Radio Emissions Designations

### Emission Classifications

Emissions are classified by the following basic characteristics:

**(1) First symbol — type of modulation of the main carrier**

(1.1) Emission of an unmodulated carrier — N

(1.2) Emission in which the main carrier is amplitude modulated (including cases where subcarriers are angle modulated)

(1.2.1) Double sideband — A

(1.2.2) Single sideband, full carrier — H

(1.2.3) Single sideband, reduced or variable-level carrier — R

(1.2.4) Single sideband, suppressed carrier — J

(1.2.5) Independent sidebands — B

(1.2.6) Vestigial sideband — C

(1.3) Emission in which the main carrier is angle modulated

(1.3.1) Frequency modulation — F

(1.3.2) Phase modulation — G

(1.4) Emission in which the main carrier is amplitude and angle modulated either simultaneously or in a pre-established sequence. — D

(1.5) Emission of pulses[1]

(1.5.1) Sequence of unmodulated pulses — P

(1.5.2) A sequence of pulses

(1.5.2.1) modulated in amplitude — K

(1.5.2.2) modulated in width/duration — L

(1.5.2.3) modulated in position/phase — M

(1.5.2.4) in which the carrier is angle modulated during the period of the pulse — Q

(1.5.2.5) which is the combination of the foregoing or is produced by other means — V

(1.6) Cases not covered above, in which an emission consists of the main carrier modulated, either simultaneously or in a pre-established sequence, in a combination of two or more of the following modes: amplitude, angle, pulse — W

(1.7) Cases not otherwise covered — X

**(2) Second symbol — nature of signal(s) modulating the main carrier**

(2.1) No modulating signal — 0

(2.2) A single channel containing quantized or digital information without the use of a modulating subcarrier[2] — 1

(2.3) A single channel containing quantized or digital information with the use of a modulating subcarrier[2] — 2

(2.4) A single channel containing analog information — 3

(2.5) Two or more channels containing quantized or digital information — 7

(2.6) Two or more channels containing analog information — 8

(2.7) Composite system with one or more channels containing quantized or digital information, together with one or more channels containing analog information — 9

(2.8) Cases not otherwise covered — X

**(3) Third symbol — type of information to be transmitted[3]**

(3.1) No information transmitted — N

(3.2) Telegraphy — for aural reception — A

(3.3) Telegraphy — for automatic reception — B

(3.4) Facsimile — C

(3.5) Data transmission, telemetry, telecommand — D

(3.6) Telephony (including sound broadcasting) — E

(3.7) Television (video) — F

(3.8) Combination of the above — W

(3.9) Cases not otherwise covered — X

The following two optional characteristics may be added for a more complete description of an emission:

**(4) Fourth symbol — detail of signal(s)**

(4.1) Two-condition code with elements of differing numbers and/or durations — A

(4.2) Two-condition code with elements of the same number and duration without error correction — B

(4.3) Two-condition code with elements of the same number and duration with error correction — C

(4.4) Four-condition code in which each condition represents a signal element (of one or more bits) — D

(4.5) Multi-condition code in which each condition represents a signal element (of one or more bits) — E

(4.6) Multi-condition code in which each condition or combination of conditions represents a character — F

(4.7) Sound of broadcasting quality (monophonic) — G

(4.8) Sound of broadcasting quality (stereophonic or quadraphonic) — H

(4.9) Sound of commercial quality (excluding categories K and L below) — J

(4.10) Sound of commercial quality with the use of frequency inversion or band-splitting — K

(4.11) Sound of commercial quality with separate frequency-modulated signals to control the level of demodulated signal — L

(4.12) Monochrome — M

(4.13) Color — N

(4.14) Combination of the above — W

(4.15) Cases not otherwise covered — X

**(5) Fifth symbol — nature of multiplexing**

(5.1) None — N

(5.2) Code-division multiplex — C

(5.3) Frequency-division multiplex — F

(5.4) Time-division multiplex — T

(5.5) Combination of frequency-division multiplex and time-division multiplex — W

(5.6) Other types of multiplexing — X

**Notes**

[1]Emissions where the main carrier is directly modulated by a signal that has been coded into quantized form (for example, pulse code modulation) should be designated under (1.2) or (1.3).

[2]This excludes time-division multiplex.

[3]In this context the word "information" does not include information of a constant, unvarying nature such as is provided by standard-frequency emissions, continuous-wave and pulse radars, and so forth.

[4]This includes bandwidth-expansion techniques.

* – Taken From Reference 3

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U) A Radio Test Bed (RTB) is currently being developed for DREO under contract. The est bed is to serve as a powerful general purpose laboratory instrument for the eneration and demodulation of non exotic communications signals found in the tactical nvironment. The system will interface with the DREO Communications Jamming Simulator to llowing jamming studies to be performed on various communications signals. The system rill have the capability of generating and demodulating the following signals: AM, FM, JSB, and LSB.

(U) A method has been devised to incorporate the generation and demodulation of data odulated Frequency Shift Keyed (FSK) signals into the RTB. The modulation technique involves using a baseband data signal to directly frequency modulate an RF carrier. Demodulation is achieved by using the FM demodulator of the RTB. Some signal conditioning is required, but the FSK generation and demodulation scheme has the capability of being easily and inexpensively implemented in the RTB while it is still under construction. The proposed method has been tested at DREO with excellent results.

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